STRATFORD/AVON RIVER ENVIRONMENTAL MANAGEMENT PROJECT

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IMPACT OF STRATFORD CITY IMPOUNDMENTS ON WATER QUALITY IN THE AVON RIVER

Technical Report S-1

Prepared by:

M. Fortin
A. Bacchus
L. Post

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PREFACE

This report is one of a series of technical reports resulting from work undertaken as part of the Stratford-Avon River Environmental Management Project (SAREMP).

This two year project was initiated in April 1980, at the request of the City of Stratford. The SAREMP is funded entirely by the Ontario Ministry of the Environment. The purpose of the project is to provide a comprehensive water quality management strategy for the Avon River basin. In order to accomplish this considerable investigation, monitoring and analysis has taken place. The outcome of these investigations and field deomonstrations will be a documented strategy outlining the program and implementation mechanisms most effective in resolving the water quality problems now facing residents of the basin. The project is assessing urban, rural and in-stream management mechanisms for improving water quality.

This report results directly from the aforementioned investigations. It is meant to be technical in nature and not a statement of policy or program direction. Observations and conclusions are those of the author and do not necessarily reflect the attitudes or philosophy of all agencies and individuals affiliated with the project. In certain cases, the results presented are interim in nature and should not be taken as definitive until such time as additional support data are collected.

Enquiries with respect to this report should be directed to:

Ontario Ministry of the Environment
985 Adelaide St. South
London, Ontario
N6E 1V3
(519) 681-3600

ABSTRACT

As part of the Stratford-Avon River Environmental Management Project, the Southwestern Regional Office of the Ontario Ministry of the Environment collected data on water chemistry and sediments at 13 stations along the Avon River during 1980 and 1981. In addition, the River Systems Unit of the Water Resources Branch, MOE, conducted an intensive in-lake survey of Lake Victoria in August 1980. Data from these surveys and other sources were used to assess the impact of Lake Victoria and the John Street weir impoundment on the water quality of the Avon River. The analysis focussed on summer impacts (May to September) since this is the period of greatest concern in this study and since the impoundments have in the past been drawn down over the winter period.

Major influences of the impoundments include increases in BOD_5 and reductions in dissolved oxygen (DO) concentrations, increases in total phosphorus and TKN, decreases of soluble phosphorus, increases in suspended solids, increases in zinc concentrations and a reduction of fecal coliform and fecal streptococci bacteria. Some of the processes that may underlie these influences are phytoplankton production, weir de-aeration, contamination from storm-sewer flows and assimilation or decay. An analysis of sedimentation rates revealed that Lake Victoria is very likely an efficient trap for suspended mineral sediments. The observed increase in suspended sediments in flows leaving the lake may therefore be caused by organic debris originating in the lake. From an analysis of bottom sediments, it was found that Lake Victoria sediments display some heavy metal contamination likely related to urban runoff.

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1. INTRODUCTION

Routine and intensive monitoring of river and lake water, and of storm sewer outfalls, had progressed into the second year of the Stratford-Avon Study when it became apparent to project staff that Lake Victoria might exert an important influence on the river downstream of Stratford. Rather than proceed to a new and separate study of this phenomenon a decision was made to reanalyze data already in hand for evidence of impacts from these impoundments. Information from these data were supplemented by analyses of potential effects based on simple models. Temperature, chemical and bacteriological impacts were analysed.

A variety of processes could have a bearing on impoundment effects. These include physical and chemical processes like sedimentation, decay, flow retention during wet weather runoff periods, weir aeration, adsorption of metals to bottom sediments, dissolution of metals from bottom sediments and thermal effects. Biological impacts related to phytoplankton and to the waterfowl population could also be important. Finally, local inflows from storm sewers might have a major impact on water quality.

Water quality and quantity data are generally available for upstream, local and downstream flows. Data within the impoundments are, however, very limited and do not permit a direct analysis of impoundment processes. As a result, much of the analysis is based on a comparison of upstream and downstream information. Conclusions about processes within the impoundments are arrived at largely by inference and must accordingly be viewed with caution.

2. DESCRIPTION OF STUDY AREA

The analysis presented in this report is restricted to the area immediately surrounding impoundments on the Avon River in the City of Stratford. Figure 1 is a map showing this area and routine monitoring stations located within it.

The dam at the downstream end of Lake Victoria, known as the Thomas Orr dam, serves to store water for recreation and to control local floods. It is a top drawing dam with a relief valve at the bottom in the event of pressure build-up behind the dam. The total capacity of the reservoir is 670 acre-feet (826,500 m^3) and normally about 300 acre-feet (370,000 m^3) of water is retained in the reservoir for recreational use. At this level, the lake is 2400 m in length. The water level in the reservoir is raised in the spring and is maintained at a more or less constant level throughout the summer and fall. The water just above the dam at the downstream end of the lake is approximately 3.7 m deep. In the recent past, the reservoir has been emptied in late fall to provide storage for flood control during the winter and spring. The current practice is to draw down the reservoir to moderate levels in the fall to preserve aesthetics and to maintain a year-round recreational facility.

The John Street Weir is a broad-crested weir with concrete abutments and vertical stop logs. It is 1.2 m in height and creates a second shallow impoundment extending from John Street back to the Thomas Orr dam. A 1.2 m^2 concrete gate in the wier structure is left open through the winter. The John Street Weir is located approximately 900 m below the Thomas Orr Dam.

The total drainage area above the John Street Weir amounts to 108 km^2 or 67% of the total Avon Basin. Of the 108 km^2, 7.3 km^2 or 6.7% is urban area drained by a storm sewer system. Most of this urban area lies below Romeo Street at the upper end of Lake Victoria. The remaining area is primarily agricultural with small woodlots and wetlands in the eastern extremeties of the basin.

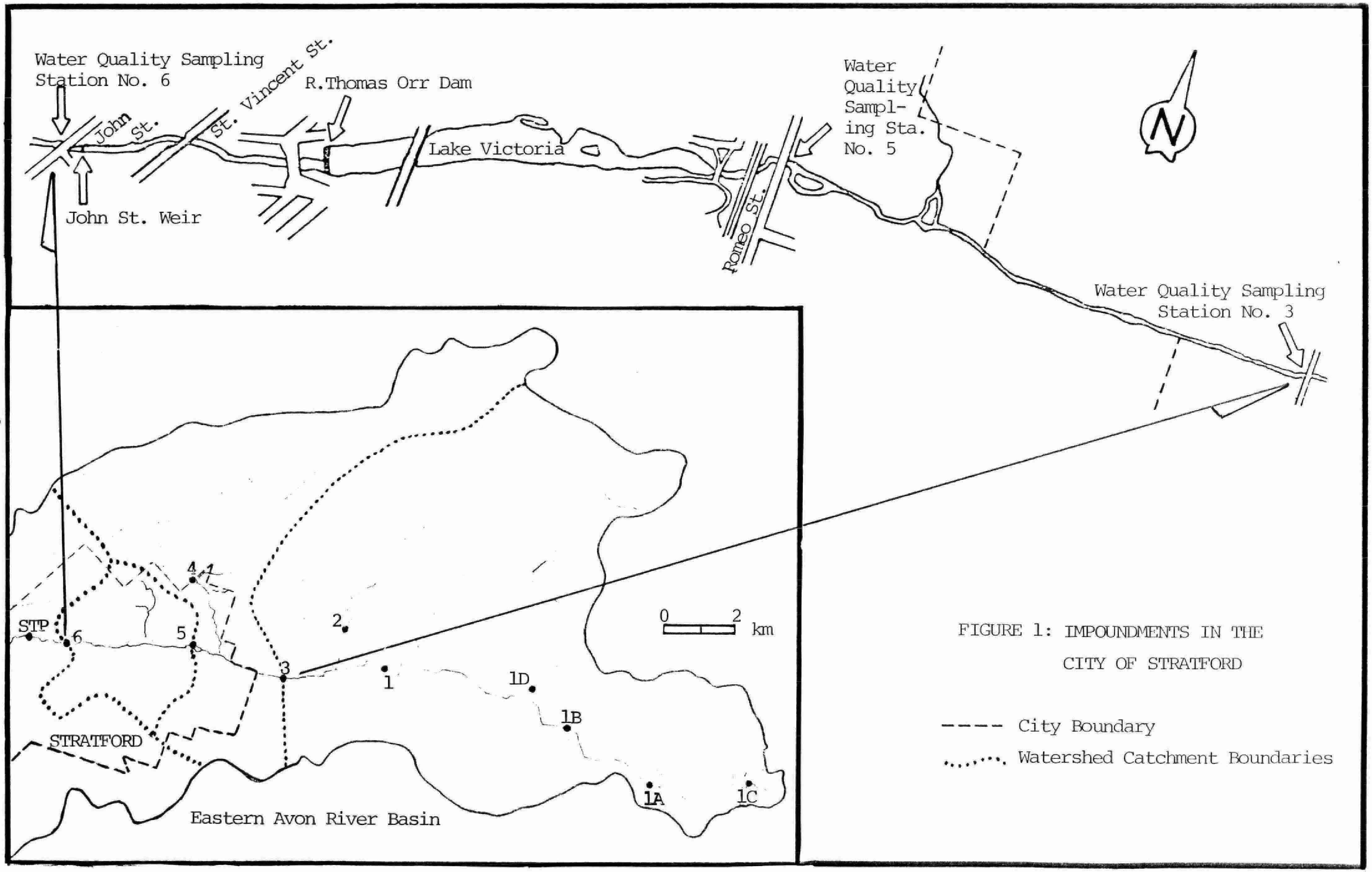

FIGURE 1: IMPOUNDMENTS IN THE CITY OF STRATFORD

3. METHODS

3.1 General

Data collection efforts related to this study included:

- 48-hour intensive water quality surveys,
- routine bi-weekly and monthly water quality sampling throughout 1980 and 1981,
- storm sewer monitoring,
- sediment sampling at routine monitoring stations,
- water quality and sediment sampling in Lake Victoria.

The analysis of data from these programs was supplemented by simple modelling efforts to estimate such factors as sedimentation rates, unit-flow yields and loadings of waterfowl excreta to Lake Victoria. Results from these different sources of information are used to outline the role of the city impoundments within the river system.

Attention is focussed on the summer period (May to September inclusive) since the impoundments are drawn down for the winter and since the water quality problems addressed by SAREMP arise primarily during the summer. Where possible, information is presented separately for wet weather and base-flow periods.

3.2 Water Quality and Sediment Sampling

The various surveys mentioned above to assay water and sediment quality are briefly described in Table 1. Sampling methods used in all cases were standard MOE practice. Sediment samples were obtained using a Ponar dredge, since piston coring of the gravelly sediments proved too difficult. All analyses of samples were carried out at the MOE main laboratory in Rexdale, or at the MOE Southwestern Region Laboratory in London, Ontario.

TABLE 1: DESCRIPTION OF WATER AND SEDIMENT SURVEYS

Survey and source document*	Survey Period	Sampling Station	Sampling Frequency	Sampling Conditions	Parameters Analyzed
Routine Monitoring (SAREMP, S-3)	1980, 1981	20 stations throughout basin	every two weeks	wet and dry weather	DO BOD_5 temp., two phosphorus, four nitrogen, three bacteria, suspended solids, chloride, conductivity, pH.
48 hr. Intensive Surveys (SAREMP, S-11)	June 16-18, 1980 July 28-30, 1980	15 stations throughout basin	every four hours	both surveys followed periods of rain.	same parameters as Routine Survey plus metals for the June survey.
Storm Sewers Survey (SAREMP, U-3)	1980, 1981	sampling near or at the outfalls of 10 storm sewered areas	intermittent sampling on a routine and intensive schedule	largely dry weather	flow, BOD_5, two phosphorus, four nitrogen, pH, suspended solids.
Lake Victoria Survey (this report)	August 26, 1980	3 stations along 5 transects on the lake (see Fig. 4)	one water and one sediment sample at each station	dry weather	water - BOD_5, TKN, two phosphorus and conductivity; sediment-loss on ignition, metals, phosphorus and nitrogen.
River Sediment Survey (SAREMP, S-7)	August 6, 1980	13 stations throughout basin	one sample at each station	not applicable	metals, phosphorus

* All SAREMP reports are listed at the end of this report.

Results from these surveys were analysed by statistical techniques and by visual examination of the data. Routine survey data were divided according to wet and dry weather flow conditions. Statistics were generated from these subsets for stations 3, 5 and 6 and the data between stations were compared using a non-parametric test, the Mann-Whitney U-Test, to check for significant differences between stations.

3.3 Supplementary Modelling

Supplementary calculations were made to assess the impacts of waterfowl excreta loadings to Lake Victoria and sedimentation in Lake Victoria.

Nutrient and BOD loadings attributed to waterfowl in the lake were calculated as daily loads in grams per kilogram of bird flesh, allowing 20 lb. (9.09 kg) weight for each swan and 3 lb. (1.36 kg) for each duck resident on the lake. Bird population sizes were estimated as 30 swans and 100 ducks and loadings were estimated as 2-4 g kg^{-1} day^{-1} BOD_5; 8 g kg^{-1} day^{-1} nitrogen as N (all forms); and .257-.428 g kg^{-1} day^{-1} phosphorus as P (all forms)*. This calculation assumes that all excreta enters the lake and that there are no losses of material to the sediments. Concentrations of each parameter are determined as average daily loading divided by average daily flow.

The analysis of sedimentation began with an estimation of residence times for flows into Lake Victoria. These are calculated simply as lake volume divided by input flow rate. A range of flow rates typical of upstream flows were used. The resulting retention values

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* These loading data were obtained from the Task Committee on Agricultural Waste Management of the Committee on Solid Waste Management of the Environmental Engineering Division, "Animal Waste Management: State of the Art," Journal of the Environmental Engineering Division, 1978.

were then used to estimate critical settling velocities for sediment using the formula:

limiting velocity = mean depth/retention time

This formulation, from Metcalf and Eddy*, is only approximate since it is meant to apply to rectangular settling basins. A discrete settling process under quiescent conditions was assumed to characterize sedimentation in the lake, so that the Stokes equation for the terminal settling velocity of a particle could be applied**. A comparison of critical settling velocities to terminal settling velocities then determines the range of particle sizes that will theoretically settle under various flow conditions.

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* Metcalf and Eddy Inc. Waste Water Engineering, McGraw-Hill Book Co., N.Y., 1972.

** W.A. Graf, Hydraulics of Sediment Transport, McGraw-Hill Book Co., N.Y., 1971.

4. RESULTS AND DISCUSSION

4.1 General

Results of the various surveys are summarized in Tables 2 to 8 and in Figures 2 to 5. Statistical analyses based on the Mann-Witney U-test are summarized in Table 3.

Inputs to Stratford City impoundments are represented by storm sewer and station 3 data and by waterfowl loading calculations. Average daily loadings from all birds were calculated to be in the order of 810-1600 g/day BOD_5, approximately 3300 g/day nitrogen as N (all forms), and 110-170 g/day phosphorus as P. The portion of this load entering the lake directly will depend on the time spent in the water by the waterfowl population.

In addition to the above mentioned upstream inputs, there is some overland flow from the park area entering the impoundments and the rural portion of the catchment above station 6 that enters the main stream below station 3. The main drain in this rural area has a monitoring station, station 4, located just north of Stratford. Data from this station, like that from all stations located upstream on small rural drains show levels of nutrients and suspended sediment that are higher than those found at stations on the main channel (SAREMP Technical Report S-3). Lower concentrations along the main channel, measured at spots like station 3, likely reflect the influence of instream processes such as sedimentation, biological uptake, adsorption, etc. They are therefore probably better measures of background water quality for waters reaching Stratford. For this reason, station 4 data is not used in this analysis.

In sections that follow, results given in the above noted tables and figures are reviewed and discussed for each parameter or set of parameters in turn.

TABLE 2: ROUTINE WATER QUALITY MONITORING RESULTS FROM MAY TO SEPTEMBER

Parameter	Statistic	Dry Weather Flows:			Wet Weather Flows:		
		STA 3	STA 5	STA 6	STA 3	STA 5	STA 6
D.O.(mg/L)	min.	7.7	7.7	4.6	6.8	5.7	7.2
	mean	10.4	9.4	8.1	11.0	9.4	9.0
	max.	13.8	11.8	10.4	14.2	13.3	11.8
Temp. (^{o}C)	mean	18.0	18.3	19.4	17.2	17.7	17.8
BOD_5(mg/l)	min.	0.7	1.1	1.7	0.8	1.1	2.0
	mean	1.0	2.7	3.3	1.9	3.9	3.8
	max.	1.5	3.6	7.6	2.7	9.4	5.8
Fecal Colif. (no./100 ml)	mean*	961	209	101	1,570	490	499
Fecal Strep. (no./100 ml)	mean*	310	41	98	335	206	332
Pseu. aer. (no./100 ml)	mean*	L4	L4	L9	L7	L15	L18
Tot.P.(mg/l)	min.	0.034	0.034	0.040	0.034	0.034	0.062
	mean	0.044	0.075	0.078	0.064	0.121	0.091
	max.	0.058	0.142	0.114	0.121	0.280	0.136
Sol.P.(mg/l)	min.	0.007	0.001	0.001	0.003	0.002	0.001
	mean	0.009	0.004	0.005	0.018	0.019	0.009
	max.	0.012	0.012	0.029	0.048	0.071	0.057
NH_3(mg/l)	mean	0.044	0.073	0.089	0.116	0.193	0.073
TKN (mg/l)	mean	0.732	1.216	1.196	0.870	1.408	1.134
NO_2 (mg/l)	mean	0.063	0.052	0.043	0.078	0.053	0.044
NO_3 (mg/l)	mean	3.24	2.55	2.52	3.45	2.31	1.84
Sus. Solids (mg/l)	min.	2.5	3.3	5.1	3.2	4.0	10.5
	mean	5.8	6.5	9.6	10.6	13.1	14.2
	max.	11.5	10.8	13.7	37.0	25.0	18.0
Ph (units)	mean*	8.07	8.16	8.11	8.03	7.99	8.06
Cond.(µmho/cm)	mean	589	606	666	573	583	598
Chloride as CL^- (mg/l)	mean	13.3	24.8	26.6	13.5	22.1	25.1

Note: L - less than

* - Geometric mean given for bacteria and pH.

TABLE 3: MANN-WHITNEY U-TEST ON ROUTINE MONITORING DATA

Parameter	Sample Size: Sta 3		Sta 5		Sta 6		Test Values For Comparisons of: Sta 3 & Sta 5:		Sta 3 & Sta 6:		Sta 5 & Sta 6:	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
D.O.	11	5	8	5	8	5	27	10.5	25.5	6.5**	26	11.5
Temp	11	5	8	5	8	5	42	12	40	10	31	10
BOD_5	6	7	6	6	8	7	10	4.5**	6**	0**	19	11
Fecal Colif.	11	5	8	5	8	5	27.5	4*	25	0*	26.5	8
Fecal Strep.	11	5	8	5	8	5	35	2*	40	4.5*	24	8
Pseu. aer.	11	5	8	5	8	5	29.5	7.5	30.5	12.5	30.5	8.5
Tot. P	11	9	8	8	8	9	20	13**	17.5**	9**	24.5	31.5
Sol. P	11	9	8	8	8	9	39.5	10*	18.5*	9*	12*	25.5
NH_3	11	9	8	8	8	9	25.5	19.5	32.5	29	10.5*	32
TKN	11	9	8	8	8	9	10.5**	5**	14**	6**	20.5	35.5
NO_2	11	9	8	8	8	9	30.5	35	19.5	30	26	27
NO_3	11	9	8	8	8	9	25	28	22	34.5	25	34.5
Sus. Solids	11	7	8	6	8	7	26.5	18	16**	8**	29	19
Ph	11	9	8	8	8	9	34.5	27	42.5	32	23.5	33
Cond.	8	6	8	6	8	6	28.5	17.5	24	9.5	27.5	12
Chloride	8	9	8	8	8	9	0**	1**	0**	1**	16	27

* first station data exceeds second station data at a 5% level of significance
** second station data exceeds first station data at a 5% level of significance

Note: The Mann-Whitney U-test uses the relative ranking of observations as evidence regarding the similarity of data sets. The resulting statistic gives evidence of significant difference when it is at or below a critical value which depends on sample size and the probability level of significance.

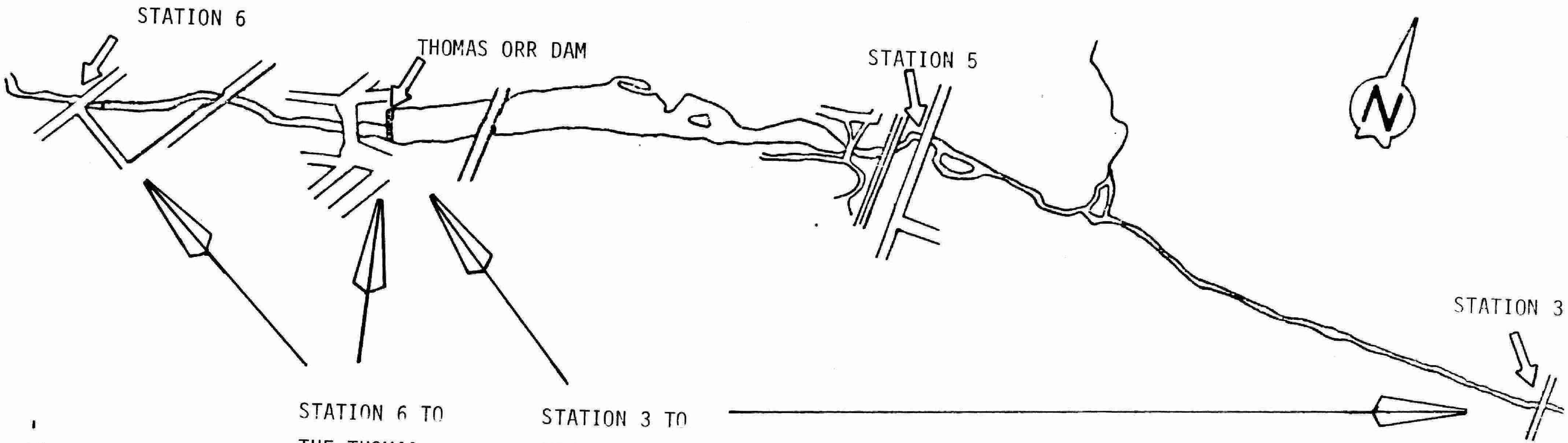
TABLE 4:. INTENSIVE WATER QUALITY SURVEY RESULTS.

Parameter	Statistic	June 16 - June 18,1980 STA 3	STA 5	STA 6	July 28 - July 30, 1980 STA 3	STA 5	STA 6
D.O.(mg/L)	min.	8.9	11.0	8.4	5.8	5.7	6.2
	mean	G13.2	G14.7	11.3	9.9	G12.6	9.8
	max.	G20.0	G20.0	14.5	18.1	G20.0	12.5
Temp. (^{o}C)	mean	14.8	14.4	16.1	19.6	21.2	22.3
BOD_5(mg/l)	min.	1.0	G5.1	2.0	1.3	2.8	3.0
	mean	2.4	G6.4	3.0	2.8	6.8	3.9
	max.	4.0	G8.0	4.8	5.8	12.0	6.4
Fecal Colif. (No./100 ml)	mean*	745	48	G168	17,600	4,660	420
Fecal Strep. (No./100 ml)	mean*	148	16	198	1,305	639	709
Pseu.aer. (No./100 ml)	mean*	L1	L1	26	71	26	44
Tot.P.(mg/l)	min.	0.033	0.140	0.054	0.062	0.091	0.74
	mean	0.092	0.234	0.074	0.144	0.195	0.098
	max.	0.225	0.384	0.104	0.336	0.254	0.128
Sol.P.(mg/l)	mean	0.097	0.006	L0.001	0.073	0.033	0.002
NH_3 (mg/l)	mean	0.050	0.296	0.034	0.277	0.288	0.348
TKN (mg/l)	mean	0.888	2.79	1.11	1.55	1.83	1.32
NO_2(mg/l)	mean	0.043	0.060	0.020	0.166	0.075	0.036
NO_3 (mg/l)	mean	2.22	1.87	2.26	3.88	1.47	0.332
Sus.Solids(mg/l)	mean	17.9	12.8	10.8	12.3	18.3	12.8
Ph (units)	mean*	8.12	7.91	8.18	7.93	7.94	8.02
Cond (µmhos/cm)	mean	553	617	675	579	534	558
Chloride as Cl^- (mg/l)	mean	12.3	23.9	25.2	18.1	21.5	24.2

Note: L - less than

G - greater than

* - geometric mean given for bacteria and pH.



	STATION 6 TO THE THOMAS ORR DAM	STATION 3 TO THE THOMAS ORR DAM
SEWERED AREA(ha)	332	396
MEAN FLOW ($m^3 sec^{-1}$)	0.033	0.041
BOD_5 (mg/l)	3.548	2.946
NH_3 (mg/l)	2.500	0.148
NO_3 (mg/l)	0.915	0.524
TKN (mg/l)	3.429	0.627
TOT. P. (mg/l)	0.227	0.253
SOL. P. (mg/l)	0.116	0.092
SUS. SOLIDS (mg/l)	4.898	7.741

FIGURE 2: DRY WEATHER STORM SEWER FLOW AND QUALITY DATA BETWEEN WATER QUALITY STATIONS 3 AND 6

TABLE 5: WATER CHEMISTRY RESULTS FROM THE LAKE VICTORIA SURVEY

Sample No.*	Total Kjeldahl Nitrogen as N (mg/L)	Total Phosphorus As P (mg/L)	Dissolved Reactive Phosphorus As P (mg/L)	Conductivity (umhos/cm)	BOD_5 (mg/L)
1L	1.45	.065	.001	500	6.2
1R	1.53	.075	.001	500	6.8
2L	1.45	.063	.001	500	6.6
2C	1.42	.068	.001	500	8.0
2R	1.58	.058	.001	500	7.8
3L	1.72	.073	.001	550	9.0
3C	1.52	.068	.001	550	7.8
3R	1.48	.068	.001	500	7.4
4L	1.48	.078	.003	500	8.0
4C	1.42	.068	.002	500	7.8
4R	1.52	.073	.001	500	7.8
5L	1.52	.060	.002	550	7.4
5C	1.51	.063	.001	550	7.6
5R	1.53	.063	.001	550	7.4

* L - approximately 8 m from left (south) bank

C - centre

R - approximately 10 m from right (north) bank

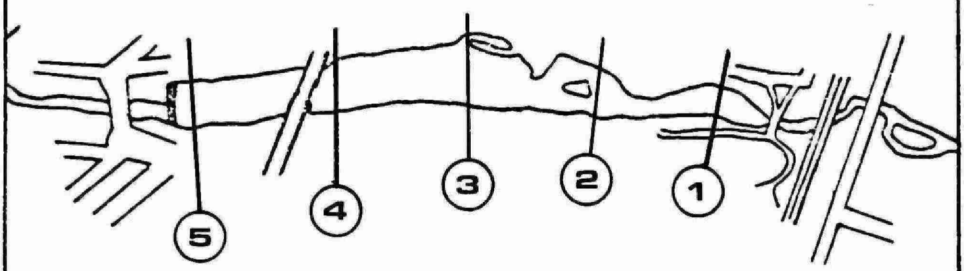


FIGURE 3 : SAMPLING TRANSECTS FOR THE LAKE VICTORIA SURVEY - August 26, 1981

4.2 Temperature

There is some evidence from both the routine and intensive surveys that there is a slight warming trend as water passes from station 3 to station 6 (Tables 2 and 4). This difference is not great, nor is it significant for the dry and wet weather routine data (Table 3). A temperature rise may be caused by the influence of industrial cooling waters discharged to the storm sewers. Alternatively, Lake Victoria and possibly the lower impoundment may act to collect solar energy and thus warm the water in its passage.

4.3 Dissolved Oxygen and BOD_5

A cursory examination of routine and intensive survey data shows that DO tends to decline from station 3 to station 6 and that BOD_5 shows an increase. The decline in DO is especially marked in the maximum values. An even sharper increase in BOD_5 is seen from station 3 to station 5 in the intensive survey data. These differences tend to be significant; especially for dry weather data (Table 3). Further evidence of elevated BOD_5 levels in Lake Victoria is found in Table 5 which documents the lake survey.

Possible sources of the BOD_5 are storm sewer flows which have concentrations higher than those of the rural flows (Table 2 and Figure 2). Possible additional sources of BOD_5 are the waterfowl (though their contributions are small when computed as a concentration*), organic debris from the large black willows (Salix nigra) that encircle Lake Victoria, and decaying cells of phytoplankton in the reservoir.

An obvious conclusion to be drawn is that the lower downstream levels of DO are the result of higher oxygen demands placed on incoming flows by elevated BOD_5 concentrations in the reservoir. This conclusion calls for some qualification, however, since weir

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* Using 150 l/sec as a typical dry weather flow, computed concentrations of waterfowl related BOD_5 are below 0.2 mg/l

aeration has a dominant influence on DO between stations 3 and 6. The John Street weir has an aeration efficiency of 88% (SAREMP Technical Report S-5). The Thomas Orr Dam would be even more efficient since it is almost three times as high. The observed drop in DO may be caused by this aeration action driving DO levels back to saturation levels. There is certainly evidence of DO supersaturation in the recorded data. The routine data in particular was measured during the day when photosynthetic production of DO would take place. For typical summer water temperatures, 19-25^{o}C, DO saturation levels range between 8.5 and 10.5 mg/l. It is likely that both BOD_5 and weir deaeration are causing the DO decline that is observed through the city impoundments.

4.4 Bacteria

Bacteria results given in Tables 2 and 4 indicate a definite and significant (Table 3) drop in fecal coliforms and fecal streptococcus through the impoundments. Rural background concentrations of these organisms tend to be quite high (SAREMP Technical Reports S-3, R-19). This decline in the reservoir could be the result of dilution by storm sewer flows or of natural die-off of these organisms. The bacteria, Pseudomonas aeruginosa, does not seem to decline like the others; rather it seems to increase somewhat. This organism, associated with human fecal contamination, could orginate from sanitary sewer or septic system connections to the city storm sewers.

4.5 Phosphorus

Phosphorus results seem to be paradoxical; during dry weather there is evidence that total phosphorus increases significantly while soluble phosphorus decreases significantly (Tables 2 and 3). Evidence provided in weather data from routine and intensive surveys is not as clear though the same trends may hold. Soluble phosphorus is 20% or more of the total at station 3 while at station 6 it falls to below 10%. This is the case despite storm sewer inflows with

soluble phosphorus concentrations amounting to 40 to 50% of total phosphorus.

The increase in total phosphorus may possibly be attributed to local contributions, notably storm sewer flows which have concentrations exceeding .2 mg/l. In fact, station 6 concentrations which are below 0.1 mg/l may point to some process other than dilution acting to lower storm sewer phosphorus concentrations. Dilution exceeding 50% is not expected since storm flows tend to dominate rural flows during dry weather periods (see section 4.7). Adsorption and sedimentation may act to remove some of the phosphorus. High phosphorus concentrations in bottom sediments support this argument (Tables 7 and 8). Obviously, the increase in total phosphorus must be attributed to the insoluble fraction since soluble phosphorus declines in the reservoir.

The loss of soluble phosphorus in the impoundments may be caused by phytoplankton uptake or by adsorption to the sediments. Uptake by macrophytes is less likely because these are not common in the impoundments. A more conclusive elucidation of the phosphorus cycle in these impoundments would require further research.

4.6 Nitrogen

Nitrogen results are more ambiguous than those for phosphorus. The only statistically significant difference is for total Kjeldahl nitrogen during both dry and wet weather; this parameter increases through the impoundment (Tables 2 and 3). A similar increase is seen in only one of the intensive surveys. A dry weather increase in NH_3, though not statistically significant (Tables 2 and 3), is nevertheless quite large and may point to the impact of elevated NH_3 concentrations in storm sewer flows (Figure 2). Both nitrite and nitrate concentrations fall from stations 3 to 6 in wet and dry

weather (Table 2). A variety of processes may account for this including*:

- reduction by phytoplankton and bacteria,
- oxidation of nitrite to nitrate, and
- uptake by phytoplankton.

As with phosphorus, insight into the nitrogen cycle in these impoundments can only come with additional research.

4.7 Suspended Solids

Suspended solids concentrations show a significant increase from stations 3 to 6 in both the wet and dry weather routine data (Tables 2 and 3). For one intensive survey, a decline is apparent while for the other, there is little change from station 3 to station 6, though station 5 is higher (Table 4). In no case is the mean concentration typical of wet weather concentrations which could range as high as several hundred parts per million.

One might expect a sedimentation process to predominate with respect to impacts on suspended solids; however, the data does not support this expectation. Rather an increase is observed. The increase may be attributed to turbulent disruption of bottom sediments by waterfowl or to phytoplankton production in the impoundments.

The influence of sedimentation should not be discounted because of these findings. The low level of suspended solids in the observed data suggests that wet weather runoff data are probably not well represented here. An alternative source of information relies on the simple sedimentation modelling discussed in Section 3.3. Results of this analysis are given in Figure 3 along with an analysis of the frequency distribution of average daily flows observed at the federal gauging station (GD018) in 1980.

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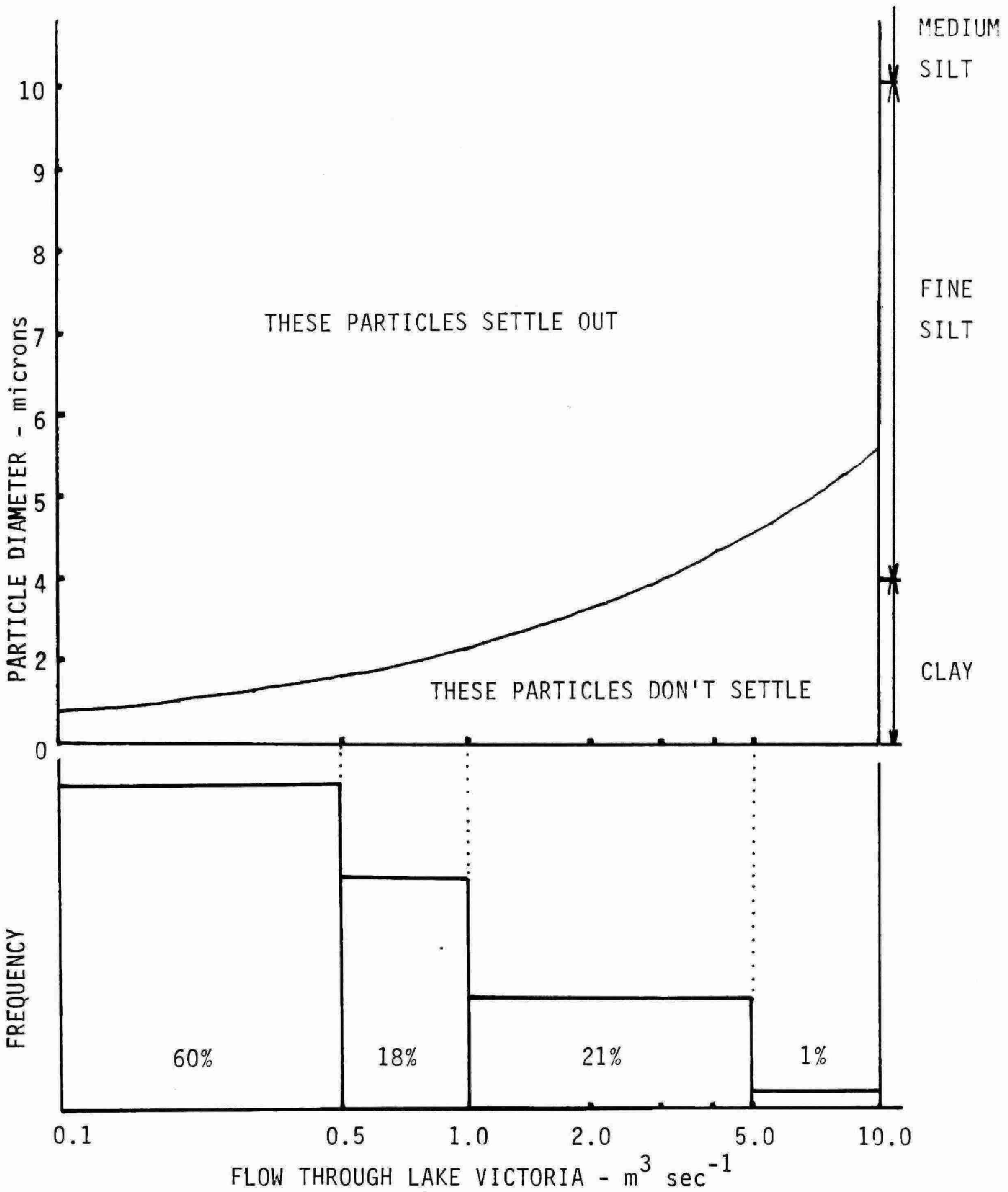
* G.E. Hutchinson, A Treatise on Limnology V.2., John Wiley and Sons Ltd., N.Y. 1957

FIGURE 4: SEDIMENTATION OF PARTICLES IN LAKE VICTORIA



Considering that Lake Victoria flows may easily be only half of the flows at the federal gauge due to the influence of the Stratford sewage treatment plant effluent, it is evident that under the majority of flow conditions, Lake Victoria could be trapping all but the finest clays.

Most of the sediment loads will be associated with the less frequent storm flows. Even these, however, are quite small (below 3 m^3 sec^{-1} generally) and capture of some of the clay fraction in Lake Victoria can still be expected. On an annual basis, the efficiency of this entrapment could be low due to the practise of complete or partial draining of the reservoir in the fall causing fine sediments to be flushed out. Bottom sediment data in Tables 7 and 8 nevertheless tend to show elevated concentrations of metals, phosphorus, nitrogen and organic matter within the reservoir, thus supporting a conclusion that sedimentation is significant.

4.8 Heavy Metals

Information on metals concentration in the water samples are quite inconclusive primarily because so many of the data points were at the lower detection limit. The most unambiguous change was observed for zinc in the routine data (Table 6). Zinc concentrations appear to increase in the reservoir. The likely source of this zinc is industry. In fact, excessive loadings of zinc to the sanitary sewers have been found from industry*. Interconnections between sanitary and storm sewers would lead to fluvial contamination from such sources.

Results of sediment samples taken on August 6 at Stations 3, 5 and 6 show levels for most measured parameters which are higher in the lake than they are upstream and downstream (Table 7). Results from the intensive Lake Victoria survey (Table 8) show that the lake

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* MaClaren Engineers, "Industrial Waste Survey and Monitoring Program - Report to City of Stratford" May, 1982.

TABLE 6: MEAN INSTREAM HEAVY METAL CONCENTRATIONS

Metal	June 16 - June 18, 1980 Intensive Survey			Routine Monitoring Program, 1981		Provincial Water Quality Objective
	Sta 3	Sta 5	Sta 6	Sta 3	Sta 6	
	- - - - - - - -	- - - - - - -	- - - -	mg/l	- - - - - - -	- - - - - - - -
Aluminum	-	-	-	0.71	0.67	-
Iron	0.385	0.260	0.280	-	-	0.300
Zinc	L0.010	L0.017	L0.013	L0.026	L0.068	0.030
Lead	L0.010	L0.010	L0.010	L0.006	L0.007	0.005-0.025*
Copper	L0.010	L0.010	L0.010	L0.020	L0.011	0.005
Nickle	L0.010	L0.010	L0.013	L0.024	L0.019	0.025
Cadmium	L0.005	L0.005	L0.005	L0.002	L0.0004	0.0002
Chromium	L0.010	L0.010	L0.010	L0.088	L0.072	0.100
Magnesium	22.3	21.7	23.1	-	-	-

* PWQO for lead is a function of alkalinity

Note: The estimated mean includes observations denoted "less than" when the giving value is preceded by "L"; such values must be interpreted as upper bounds on the population mean rather than an estimate of the mean.

TABLE 7: SEDIMENT DATA FOR THE ROUTINE MONITORING STATIONS

Station	3	5	6
zinc (Zn)	35	77	37
copper (Cu)	9.5	20	11
nickle (Ni)	7	16	6
lead (Pb)	5	34	190
cadmium (Cd)	L0.3	0.3	0.55
chromium (Cr)	15	23	12
aluminum (Al)	6,100	16,000	2,100
molybdenum (Mo)	L2	L2	3.5
cobalt (Co)	4	8	3
selenium (Se)	L0.3	0.3	L0.3
arsenic (As)	3.5	5.9	1.5
mercury (Hg)	0.02	0.10	L0.01
manganese (Mn)	280	470	260
iron (Fe)	11,000	18,000	14,000
total phosphorous (P)	560	840	260
total nitrogen (N)	1,200	2,100	190
loss on ignition (LOI)- %	3.9	8.3	1.1

Note:- all units in micrograms per gram unless given otherwise

- L denotes "less than"

TABLE 8: SEDIMENT DATA FROM THE LAKE VICTORIA SURVEY

Sample No.	Zn	Cu	Ni	Pb	Cd	Cr	Mo	Co	Se	Ap	Hg	Total P	Sol. P	Total N	LOI (%)
1L	1500	170	19	170	1.6	110	2.5	5	.3	4.4	.060	1000	480	2300	6.17
1R	3200	220	19	290	4.5	150	2	7.5	.5	3.0	.078	1000	520	2600	7.70
2L	68	13	10	8.3	0.3	21	2	5.5	.3	5.9	.046	930	120	1100	4.24
2C	500	64	9.3	58	0.78	44	2	3.5	.4	3.0	.056	740	260	2200	6.40
2R	72	18	10	25	0.3	20	2	5.5	.8	5.0	.055	830	240	2300	7.21
3L	90	18	14	24	0.45	31	2	8.3	.5	4.9	.089	840	220	2200	7.35
3C	750	99	20	120	1.3	70	3.5	8	.5	4.6	.089	1100	420	2800	8.12
3R	930	96	16	87	2.9	79	2.5	6.3	.4	4.6	.063	1100	510	2900	6.35
4L	490	74	29	98	1	70	2	11	.5	6.4	.10	1600	710	4600	11.55
4C	1000	130	15	130	1.2	84	2	5.5	.3	3.8	.074	970	400	2500	5.84
4R	970	120	18	130	1.6	83	2	9	.5	4.9	.092	1200	540	3300	8.03
5L	630	87	19	98	1	67	2	6.5	.5	4.2	.14	1500	40	4600	9.40
5C	1000	110	20	120	1.3	77	2	7.3	.5	5.0	.087	1200	500	3800	8.31
5R	580	80	15	87	0.93	59	2	5.5	.4	3.8	.065	1100	370	2600	6.76

Note: All units are micrograms per gram unless given otherwise.

TABLE 9: CLASSIFICATION OF GREAT LAKES SEDIMENTS*

	Nonpolluted Upper Limit	Moderately Polluted	Heavily Polluted Lower Limit
	- - - - - - - - - -	micrograms/gram	- - - - - - -
TKN	1,000	1,000- 2,000	2,000
Pb	40	40-60	60
Zn	90	90-200	200
Hg	1.0	-	1.0
P	420	420-650	650
Fe	17,000	17,000-25,000	25,000
Ni	20	20-50	50
Mn	300	300-500	500
Cr	25	25-75	75
Cu	25	25-50	50

* Taken from the "Hamilton Harbour Study Report", Lake Systems Unit, Water Modelling Section, Water Resources Branch, Ontario Ministry of the Environment, Toronto, August 1977, p.c-6.

sediments show unacceptable levels of zinc, copper, lead, phosphorus and chromium. Only lead in the river sediments below Stratford had concentrations falling into the heavily polluted category.

The variety of constituents found in more concentrated form in lake sediments suggests that sedimentation is significant in the lake, as was mentioned above. Constituents in the bottom sediments likely come from a variety of sources. Phosphorus and nitrogen likely are carried into the reservoir with material eroded from cultivated areas above Stratford. Most of the heavy metals have likely come from industrial sources in the city. The exception is lead which could be associated with the burning of leaded fuels in vehicles. Particulate exhaust materials would wash off roads and into the river and lake during storms. The presence of lead in sediments at the rural stations, which are all located at road crossings, would support this hypothesis.

4.9 Distribution of Sediment and Water Constituents in Lake Victoria

The Lake Victoria survey generated information given in Tables 5 and 8 and in Figure 5. Water chemistry results are quite uniform and suggest fairly thorough mixing throughout the Lake. This is not so for sediment results, the heavy metals in particular. Concentrations are considerably higher at the upstream end (Figure 5). Storm sewer outfalls above the first transect drain an industrialized area of Stratford lying south of the river. The elevated metals concentrations in the sediment at the first transect may reflect the comulative impact of sediment adsorption of metals from this industrial section. Elevated levels of organic matter (LOI) and phosphorus along the south (left) bank of the reservoir at transects 4 and 5 suggest an accumulation of organic debris along the lower south side of the lake. This may be associated with the grove of black willows (*Salix nigra*) overhanging the water along the south bank.

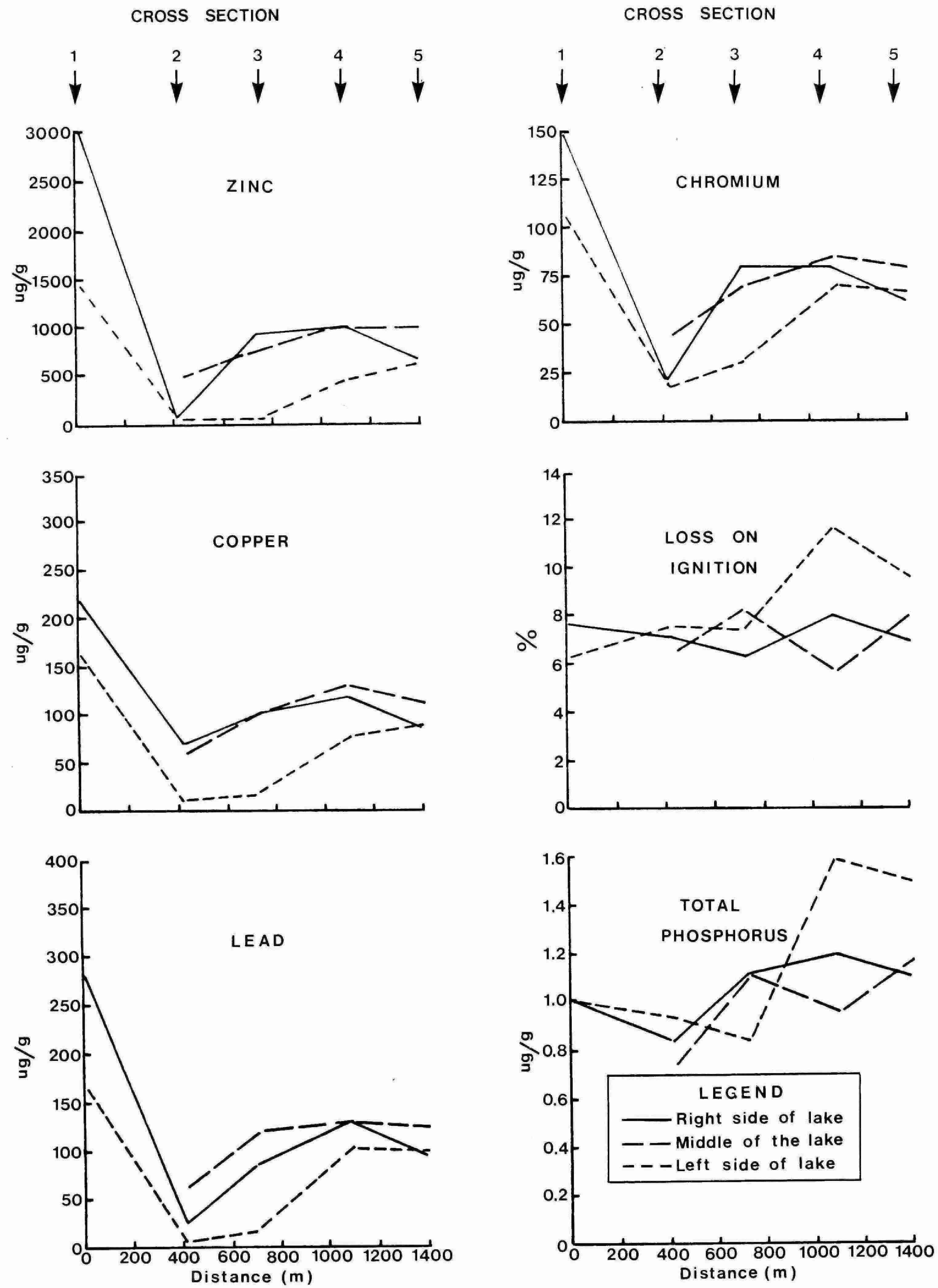

FIGURE 5. SPATIAL DISTRIBUTION OF SELECTED PARAMETERS IN LAKE VICTORIA SEDIMENTS

5. CONCLUSIONS

Notable water quality impacts of Lake Victoria during the summer include:

- increase of BOD_5 and reduction of dissolved oxygen,
- reduction of certain indicator bacteria,
- loss of soluble phosphorus and increase of total phosphorus,
- an increase of total Kjeldahl nitrogen,
- an increase of suspended solids (likely organic matter)
- sedimentation of mineral sediments,
- increase in zinc concentrations.

These impacts can likely be attributed to local inflows from the storm sewers carrying urban runoff and industrial discharges, to processes in the impoundment such as the production of phytoplankton and sedimentation and to weir de-aeration.

There is some lead contamination of Lake Victoria and downstream sediments. This is likely associated with runoff from roads or industrial discharges to storm sewers. Contamination of lake sediments with zinc, copper, chromium and phosphorus is also evident.

STRATFORD-AVON RIVER ENVIRONMENTAL MANAGEMENT PROJECT
LIST OF TECHNICAL REPORTS

S-1 Impact of Stratford City Impoundments on Water Quality in the Avon River
S-2 Physical Characteristics of the Avon River
S-3 Water Quality Monitoring of the Avon River - 1980, 1981
S-4 Experimental Efforts to Inject Pure Oxygen into the Avon River
S-5 Experimental Efforts to Aerate the Avon River with Small Instream Dams
S-6 Growth of Aquatic Plants in the Avon River
S-7 Alternative Methods of Reducing Aquatic Plant Growth in the Avon River
S-8 Dispersion of the Stratford Sewage Treatment Plant Effluent into the Avon River
S-9 Avon River Instream Water Quality Modelling
S-10 Fisheries of the Avon River
S-11 Comparison of Avon River Water Quality During Wet and Dry Weather Conditions
S-12 Phosphorus Bioavailability of the Avon River
S-13 A Feasibility Study for Augmenting Avon River Flow by Ground Water
S-14 Experiments to Control Aquatic Plant Growth by Shading
S-15 Design of an Arboreal Shade Project to Control Aquatic Plant Growth

U-1 Urban Pollution Control Strategy for Stratford, Ontario - An Overview
U-2 Inflow/Infiltration Isolation Analysis
U-3 Characterization of Urban Dry Weather Loadings
U-4 Advanced Phosphorus Control at the Stratford WPCP
U-5 Municipal Experience in Inflow Control Through Removal of Household Roof Leaders
U-6 Analysis and Control of Wet Weather Sanitary Flows
U-7 Characterization and Control of Urban Runoff
U-8 Analysis of Disinfection Alternatives

R-1 Agricultural Impacts on the Avon River - An Overview
R-2 Earth Berms and Drop Inlet Structures
R-3 Demonstration of Improved Livestock and Manure Management Techniques in a Swine operation
R-4 Identification of Priority Management Areas in the Avon River
R-5 Occurrence and Control of Soil Erosion and Fluvial Sedimentation in Selected Basins of the Thames River Watershed
R-6 Open Drain Improvement
R-7 Grassed Waterway Demonstration Projects
R-8 The Controlled Access of Livestock to Open Water Courses
R-9 Physical Characteristics and Land Uses of the Avon River Drainage Basin
R-10 Stripcropping Demonstration Project
R-11 Water Quality Monitoring of Agricultural Diffuse Sources
R-12 Comparative Tillage Trials
R-13 Sediment Basin Demonstration Project
R-14 Evaluation of Tillage Demonstration Using Sediment Traps
R-15 Statistical Modelling of Instream Phosphorus
R-16 Gully Erosion Control Demonstration Project
R-17 Institutional Framework for the Control of Diffuse Agricultural Sources of Water Pollution
R-18 Cropping-Income Impacts of Management Measures to Control Soil Loss
R-19 An Intensive Water Quality Survey of Stream Cattle Access Sites